BUCKLING ANALYSIS OF LAMINATED COMPOSITE PLATES

A Thesis Submitted in Partial Fulfilment of the Requirements for the degree of

Bachelor of Technology
In
Mechanical Engineering

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(Department Of Mechanical Engineering)

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CERTIFICATE

This is to certify that the thesis entitled, "**BUCKLING ANALYSIS OF LAMINATED COMPOSITE PLATES"** submitted by Mr **Praseed Sahu** in partial fulfilment of the requirement for the award of **Bachelor of Technology** Degree in **Mechanical Engineering** with specialization in **Mechanical Engineering** at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

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ABSTRACT

Laminated composites have been used in many engineering structures from early time the recent advancements in material technology has led to the creation of a new composite with enhanced properties. Composite materials are generally used in many fields of engineering like buildings, bridges, boat hulls, swimming pool panels, race car bodies, shower stalls, bathtubs and storage tanks. In addition to that industries where weight reduction is of prime concern (aviation and spacecraft etc.). Composites are capable enough to take different types of loading both tensile and compressive based on the requirement. It is well known that the structural elements under compressive loads and/or due to thin built up they may be prone to buckle. In order to evaluate the buckling strength of laminated structures many studies has already been completed numerically and experimentally. A lab scale buckling test rig has been developed to obtain the critical load. In addition to that a simulation study has been done in ANSYS using ANSYS parametric design language. Some new results have been obtained for different parameter and discussed in detail.

Keywords: Buckling, Laminated composites, Experimental analysis, FEM, ANSYS

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

There are many types of failures in engineering structures. Some of them include creep, fatigue, alternate stresses, bending, buckling etc. Buckling takes place in columns, plates, shells, and other structures of regular or irregular geometry. In this project only buckling of laminated composite plates has been considered. If the loads applied to a flat plate are low then there is low no observed distortion of the plate however as the load is increased then the equilibrium configuration of the plate changes into no flat configuration. Thus the plate in the case becomes unstable. The minimum load at which the equilibrium is disturbed is called as the critical buckling load.

A composite has dual character. It is made up of two or more materials which when combined give different properties than their original characteristics. These materials have important properties like they are light in weight because the combined properties give rise to significant weight loss character. Thus they have high strength and high stiffness compared to their weight.

Also in a composite the properties are affected by the degree of composition of the parent materials. Thus the properties can be altered by changing the composition of the composite. In composites the two components are called as fibre and matrix. The fibres are the main load bearing members and the matrix, which has low modulus and high elongation, provides the necessary flexibility and also keeps the fibres in position and protect them from the environment.

As discussed in the previous paragraph, flexibility is one of the major advantage of composite which in turn creates the necessity and requirement of the analysis of the structure. The properties of such materials depend on the constituent materials, their distribution in the matrix and their orientation in the composite. Thus a new material with unusual combination can be obtained with properties that are dissimilar to the parent constituents.

Some of the uses of laminated composite plates are in critical areas of infrastructure like aviation, waterways, military, structures etc. In most of these cases the fibre reinforced composites are not in the form of columns but thin flat plates which carry axial compressive loads. During their operating period the compressive loads may exceed a safety value and this may cause buckling of the composite plates which can cause catastrophic failures. Many theoretical computations are there which formulate the behaviour of such composites under loads and solving them gives the critical buckling load. But such computations tend to be cumbersome and lengthy. To avoid these technicalities experimental methods are much preferred. This study aims to develop an indigenous setup which can estimate the critical buckling load.

LITERATURE REVIEW

In 1964 Schlack [3] analysed the buckling behaviour of a simple supported square plate with a circular hole was analysed by applying Rayleigh- Ritz method. Martin [4] in 1972 presented the buckling of square composite plates having a cut out that are subjected to uniaxial compression. In 1986 results for buckling of orthotropic rectangular plates with longitudinally eccentric circular cut-out was presented by Marshall, Little, El-Tayeby, and Williams [5]. In 1987 Nemeth, Stein, and Johnson [6] analysed the buckling behaviour of square orthotropic graphite – epoxy plates that have a central circular cut-out and gave additional analytical results. In 1989 Lee [7] used the finite element method (FEM) to examine the buckling behaviour of square plate with a central circular hole. A buckling behaviour of sequence laminated composite plate, each with a central circular cut-out was presented by Lin and Kuok [8] in 1989. The mechanical and thermal buckling behaviour of rectangular steel plates with central circular and square cutout was studied by William [9]. In 1990 Rouse [10] presented an experimental investigation of the buckling and post buckling behavior of square graphite-epoxy and graphite – thermoplastic plates loaded in shear. In 1991 Yaqui [11] described the study of buckling behaviour of laminated composite plates with a central cutout that has been obtained by using the finite element method. In 2004 [12] Jameel studied the buckling behavior of an elastic plate with circular hole.

From the above literatures, it can be seen that many studies has been reported on buckling analysis of laminated composites numerically and experimentally as well. It is also observed that some of the studies have been done with the help of commercial finite element (FE) tool like ANSYS, ABAQUS and NASTRAN etc. It is understood that the numerical study using commercial FE tool not only easy to model but also less time expensive. Hence, the objective of the present work has been stated in following paragraph based on the above observation.

AIM AND SCOPE OF PRESENT WORK

As discussed earlier, the thin laminated composite plates are capable to carry extra amount of load under compressive loading. It is well known that the structures under compressive loading may lose their stability and a geometric instability induced in the structure which in turn say, buckling of the structure.

To achieve the same majority of work has been carried out in modelling and numerical investigation of the buckling behaviour of the laminated composite plates time to time. It is also true that the experimental methods however are not too easy to implement. It is because of the fact that fabrication of composite plate by maintaining the required properties for which they have been the quest of design engineers as well as available INSTRON machine which are very costly. Hence, the present project aims at develop an lab scale buckling test rig using hydraulic pressure to calculate the critical buckling load of various laminated plate. It is worthy to mention that the required specimens have been prepared using hand lay-up technique. Finally, the results are also obtained numerically using commercial finite element software.

CHAPTER 2

THEORETICAL FORMULATION AND MODELLING

THEORETICAL FORMULATION

The buckling phenomenon of a plate includes two boundary conditions on each edge of a plate. The buckling characteristic of a plate and a column is very different. In case of a column the critical buckling load is the failure load i.e. the column fails at the buckling load but in case of a plate the failure load is around 10-15 times that of the critical buckling load. In some cases failure does not occur in the plates even at these loads.

THEORY OF BENDING OF THIN PLATES

Bending of thin plates is in many ways similar to the bending of beams. In pure bending of beams, "the stress distribution is obtained by assuming that cross-sections of the plate remains plane during bending and only rotate w.r.t. their neutral axes so that it is always normal to the deflection curve."

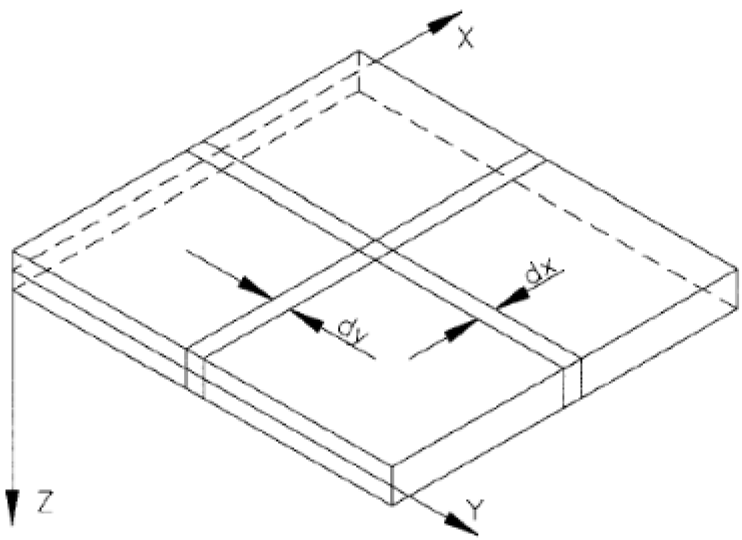


Figure 1
Axis definition of a laminate composite plate [2]

The assumptions in elastic bending are:

- The plate material is linear and follows the Hooke's law.
- The plate is completely flat and is of uniform thickness throughout the cross section.
- The thickness of the plate is small compared to the length and breadth of the plate. Therefore normal stress in transverse direction can be neglected compared to normal stress in plane of plate.
- The deflection that the plate undergoes is very small, generally around half of the thickness.
- The stress in the mid plane of the plate is zero and it behaves as the neutral plane.
- The application of load is normal to the centre plane of the plate.
- The applied load is resisted by the bending and twisting of the plate. The shearing effects are neglected.
- Like bending in a beam the stresses and strains are proportional to their distances from the neutral surfaces.

Composite materials

Composites are materials which are prepared by the combination of two or more materials and the properties of the composites are markedly different from the properties of the parent materials. Composite laminates are sum total of layers of fibres which can be assembled to give required material properties which includes in-plane stiffness, bending stiffness, strength, and coefficient of thermal expansion. In laminated composite plates the orientation of the matrix is very important as it gives different properties.

Each layer of the fibre reinforced composite plate is called as a lamina. Lamina is a macro component of a laminate and its properties are dependent on the stacking sequence and the hardener used. Its properties are derived experimentally. Structural elements such as beams, bars and plates are generated by assembling the layers to achieve desired strength and stiffness. The orientation of the fibres and the stacking sequence give the laminate the desired strength and stiffness.

Governing Equations

A laminate is produced by using laminas which are stacked in sequences to obtain the laminate. The properties of the laminate like its stiffness is obtained by knowing the properties of the constituent materials. To know this the orientation of the principal matrix element must be known. Therefore we must know the directions of stress and strain through the lamina.

To study the behaviour of the laminates we assume the following:

- The bonds in the laminate are strong and perfect.
- The bonds are very thin and slippage between the laminar layers do not occur. This means that the displacements are not discontinuous across the laminas boundaries.
- The strain normal to the neutral surface is ignored.
- Post buckling the line which is straight and normal to the mid plane remains straight and mid plane.

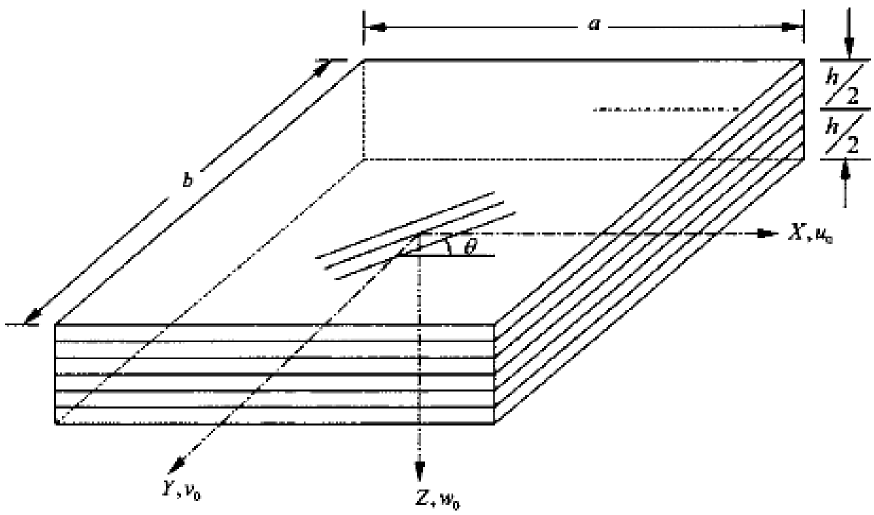


Figure 2
Layers of a laminate composite plate [2]

To derive the governing buckling equations we here consider the classical laminate theory. We consider the equilibrium of the forces and the moments to derive the governing equations of buckling. [2]

Balancing the forces the equilibrium equation can be written as (Figure 2):

$$\frac{\delta N_x}{\delta x} + \frac{\delta N_{xy}}{\delta y} = 0$$

$$\frac{\delta N_{xy}}{\delta x} + \frac{\delta N_y}{\delta y} = 0 \qquad \ldots\ldots\ldots (1)$$

Where *Nxy; Ny;* and *Nx* are the forces which act inside the ply in perpendicular direction and tangential direction.

Balancing the moments the equilibrium equation can be written as (Figure 2):

$$\frac{\partial^2 M_x}{\partial x^2} + 2\frac{\partial^2 M_{xy}}{\partial x \partial y} + \frac{\partial^2 M_y}{\partial y^2} + N_x \frac{\partial^2 w}{\partial x^2} + N_y \frac{\partial^2 w}{\partial y^2} + 2N_{xy}\frac{\partial^2 w}{\partial x \partial y} = 0 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where, *Nx ;Ny; Nxy* are the forces acting on the edge of the plate.

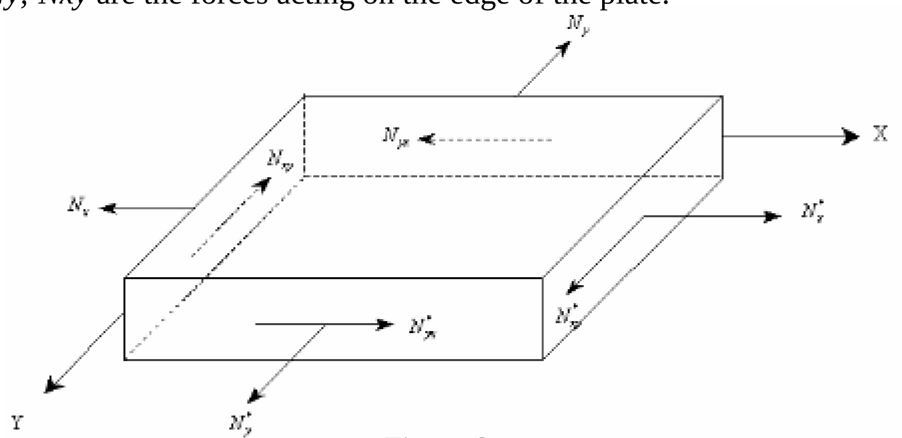


Figure 3
Forces acting on the plate [2]

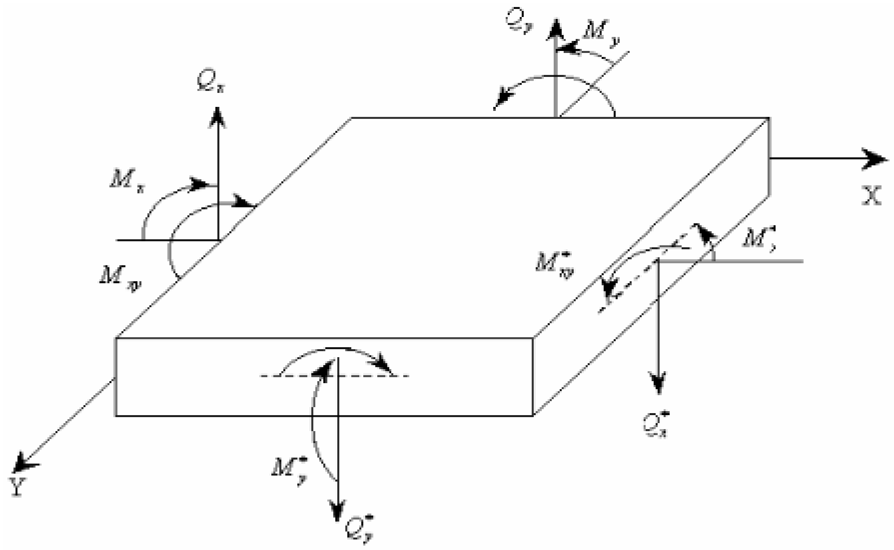


Figure 4 : Moments acting on the plate [2]

The resultant forces *Nx; Ny* and *Nxy* and moments *Mx; My* and *Mxy* can be obtained bt integrating the stress acting on each layer through the thickness of the plate. Knowing the stress in terms of the displacement, the stress resultant can be obtained as follows in terms of *Mx ; My ;* and *Mxy*., *Nx; Ny; Nxy;*

The stress resultants are defined as:

$$N_x = \int_{-t/2}^{+t/2} \sigma_X \, dz \quad N_y = \int_{-t/2}^{+t/2} \sigma_y dz \quad N_{xy} = \int_{-t/2}^{+t/2} \tau_{xy} dz$$

$$M_x = \int_{-t/2}^{+t/2} \sigma_x z dz \quad M_y = \int_{-t/2}^{+t/2} \sigma_y z dz \quad M_{xy} = \int_{-t/2}^{+t/2} \tau_{xy} z dz \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Where σ_x , σ_y and τ_{xy} are normal and shear stress.

Strictly speaking the above forces are the forces which are shown in Figure 3 act per unit length of the laminate. Similarly, the above moments as shown in Figure 4 act per unit length of the laminate. Thus, the forces and moments for an N-layer laminate can be defined as**:**

$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \end{Bmatrix} = \int_{-h/2}^{h/2} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix}_r dz = \sum_{r=1}^{N} \int_{Zr-1}^{Zr} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix}_r dz \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

$$\begin{Bmatrix} M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \int_{-h/2}^{h/2} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix}_r zdz = \sum_{r=1}^{N} \int_{Zr-1}^{Zr} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix}_r zdz \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

Z_r and Z_{r-1} can be defined as in the figure below:

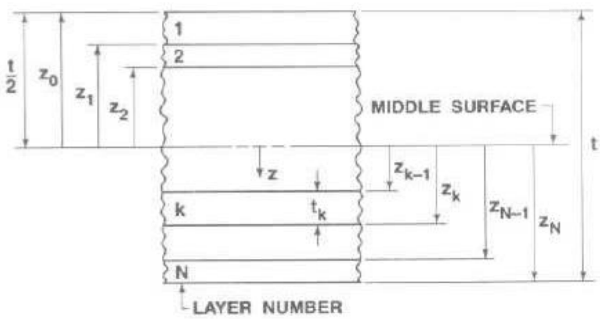


Figure 5: Laminated composite plate with detail layer number [2]

We must note that z_0=-t/2. Substituting for σ_x, σ_y and τ_{xy} in in equations (2) and (3) and integrating over the thickness of each layer and adding the results so obtained for N layers, we can write the stress resultants as:

$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ A_{12} & A_{22} & A_{26} \\ A_{16} & A_{26} & A_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon^0{}_x \\ \varepsilon^0{}_y \\ \gamma^0{}_{xy} \end{Bmatrix} + \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ B_{12} & B_{22} & B_{26} \\ B_{16} & B_{26} & B_{66} \end{bmatrix} \begin{Bmatrix} k_x \\ k_y \\ k_{xy} \end{Bmatrix}$$

$$\begin{Bmatrix} M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ B_{12} & B_{22} & B_{26} \\ B_{16} & B_{26} & B_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon^0{}_x \\ \varepsilon^0{}_y \\ \gamma^0{}_{xy} \end{Bmatrix} + \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{12} & D_{22} & D_{26} \\ D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{Bmatrix} k_x \\ k_y \\ k_{xy} \end{Bmatrix} \text{ ………………………. (6 and 7)}$$

Where:

$$A_{ij} = \sum_{r=1}^{N} (\overline{Q}_{ij})_r (Z_r - Z_{r-1}),$$

$$B_{ij} = 1/2 \sum_{r=1}^{N} (\overline{Q}_{ij})_r (Z^2{}_r - Z^2{}_{r-1}),$$

$$D_{ij} = 1/3 \sum_{r=1}^{N} (\overline{Q}_{ij})_r (Z^3{}_r - Z^3{}_{r-1}) \text{ ...………………………….. (8)}$$

Here, *Aij* denotes the extensional stiffness, Bij *denotes* the coupling stiffness, and Dij denotes the flexural stiffness. For antisymmetric laminates stress resultants are simplified in the following sections:

In the case of angle-ply laminates where the fibre orientation θ alternates from lamina to lamina as [$\pm\theta$], the force and moment resultants are

$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & 0 \\ A_{12} & A_{22} & 0 \\ 0 & 0 & A_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon^0{}_x \\ \varepsilon^0{}_y \\ \gamma^0{}_{xy} \end{Bmatrix} + \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ B_{12} & B_{22} & B_{26} \\ B_{16} & B_{26} & B_{66} \end{bmatrix} \begin{Bmatrix} k_x \\ k_y \\ k_{xy} \end{Bmatrix} \text{………………………. (9)}$$

$$\begin{Bmatrix} M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ B_{12} & B_{22} & B_{26} \\ B_{16} & B_{26} & B_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon^0{}_x \\ \varepsilon^0{}_y \\ \gamma^0{}_{xy} \end{Bmatrix} + \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{12} & D_{22} & D_{26} \\ D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{Bmatrix} k_x \\ k_y \\ k_{xy} \end{Bmatrix} \text{ …………………….. (10)}$$

Such a laminate is called an anti-symmetric angle-ply laminate. If each layer in a lamina has the same thickness then it is called a regular anti-symmetric angle-plylaminate. For such a laminate, equations (6) and (7) reduce to:

$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & 0 \\ A_{12} & A_{22} & 0 \\ 0 & 0 & A_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon^0{}_x \\ \varepsilon^0{}_y \\ \gamma^0{}_{xy} \end{Bmatrix} + \begin{bmatrix} 0 & 0 & B_{16} \\ 0 & 0 & B_{26} \\ B_{16} & B_{26} & 0 \end{bmatrix} \begin{Bmatrix} k_x \\ k_y \\ k_{xy} \end{Bmatrix} \text{……………..} (11)$$

$$\begin{Bmatrix} M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} 0 & 0 & B_{16} \\ 0 & 0 & B_{26} \\ B_{16} & B_{26} & 0 \end{bmatrix} \begin{Bmatrix} \varepsilon^0{}_x \\ \varepsilon^0{}_y \\ \gamma^0{}_{xy} \end{Bmatrix} + \begin{bmatrix} D_{11} & D_{12} & 0 \\ D_{12} & D_{22} & 0 \\ 0 & 0 & D_{66} \end{bmatrix} \begin{Bmatrix} k_x \\ k_y \\ k_{xy} \end{Bmatrix} \text{……………..} (12)$$

Let the laminae are oriented relatively at 0^o and 90^o. A laminate of this type is termed as a cross-ply laminate. Such a laminate can, again, be either symmetric cross-ply or antisymmetric cross-ply.

Substituting for N_{xy}, N_y, N_x, M_x, M_y and M_{xy} from equations 9 and 10 after substituting for $\varepsilon^0{}_x$, $\varepsilon^0{}_y$ and $\gamma^0{}_{xy}$, k_x, k_y and k_{xy} in equations 1 and 2 we get the governing equations as follows :

$$A_{11}\frac{\partial^2 u^0}{\partial x^2} + (A_{12}+A_{66})\frac{\partial^2 v^0}{\partial x \partial y} + A_{16}(\frac{\partial^2 u^0}{\partial x^2} + 2\frac{\partial^2 u^0}{\partial x \partial y}) + A_{26}\frac{\partial^2 v^0}{\partial y^2} + A_{66}\frac{\partial^2 u^0}{\partial y^2} - B_{11}\frac{\partial^3 w}{\partial x^3} - 3B_{16}\frac{\partial^3 w}{\partial x^2 \partial y}$$
$$-(B_{12}+2B_{66})\frac{\partial^3 w}{\partial x \partial y^2} - B_{26}\frac{\partial^3 w}{\partial y^3} = 0$$

$$A_{16}\frac{\partial^2 u^0}{\partial x^2} + (A_{12}+A_{66})\frac{\partial^2 u^0}{\partial x \partial y} + A_{26}\frac{\partial^2 u^0}{\partial y^2} + A_{66}\frac{\partial^2 v^0}{\partial x^2} + 2A_{26}\frac{\partial^2 v^0}{\partial x \partial y} + A^{22}\frac{\partial^2 v^0}{\partial y^2} - B_{16}\frac{\partial^3 w}{\partial x^3} - (B_{12}+2B_{66})\frac{\partial^3 w}{\partial x^2 \partial y}$$
$$-3B_{26}\frac{\partial^3 w}{\partial x \partial y^2} - B_{22}\frac{\partial^3 w}{\partial y^3} = 0$$

$$D11\frac{\partial^4 w}{\partial x^4} + 4D_{16}\frac{\partial^4 w}{\partial x^3 \partial y} + (2D_{12}+4D_{16})\frac{\partial^4 w}{\partial x^2 \partial y^2} + 4D_{26}\frac{\partial^4 w}{\partial x \partial y^3} + D_{22}\frac{\partial^4 w}{\partial y^4} - B_{11}\frac{\partial^3 u^0}{\partial x^3} - 3B_{16}\frac{\partial^3 u^0}{\partial x^2 \partial y} - (B_{12}+2B_{66})\frac{\partial^3 u^0}{\partial x^2 \partial y}$$
$$-B_{26}\frac{\partial^3 u^0}{\partial y^3} - B_{16}\frac{\partial^3 v^0}{\partial x^3} - (B_{12}+2B_{66})\frac{\partial^3 v^0}{\partial x \partial y^2} - B_{22}\frac{\partial^3 v^0}{\partial y^3} = -N_x\frac{\partial^2 w}{\partial x^2} - N_y\frac{\partial^2 w}{\partial y^2} - 2N_{xy}\frac{\partial^2 w}{\partial x \partial y}$$

All the three equations need to be solved for a general laminate as they are coupled.

CHAPTER 3

EXPERIMENTAL STUDY

NEED FOR EXPERIMENTS

Many numerical and mathematical models exist which can be used to describe the behaviour of a laminate under the action of different forces. When it comes to buckling we can develop a mathematical model which can be used to model the phenomenon of buckling. But numerical methods become complicated as the number of assumptions decrease and the number of variables increase. Also once the model is formed it takes a lot of time to solve the partial differential equations and then arrive at the final result. This process becomes very cumbersome and time consuming. In view of the above mentioned laminations experimental methods are followed. The experimental processes need less time and less computational work is involved in that. Also the result obtained in experiments is very close to that which is obtained theoretically.

PRESENT EXPERIMENTAL SETUP

Earlier experiments have been conducted to determine the critical buckling load of the laminated composite plates. But most of these experiments have been conducted on INSTRON test machines. The INSTRON test machines cost very much and also they are not flexible as once they have been installed they cannot be moved from place to place. So in this work an indigenous buckling setup has been devised with minimum cost so that the buckling tests can be performed at much low costs. Also the setup is flexible and can be assembled at any place where the test is to be carried out. The setup can also be extended to do tension tests with suitable modifications.

PREPARATION OF THE LAMINATED COMPOSITE PLATES

Composites are used in almost all disciplines of engineering. As such there are many processes to prepare composites. Research is also going on in industries to prepare composites much faster and the most economical way. Most of these methods have their own set of advantages and disadvantages. The two most popular methods which are there for the preparation of composites are hand layup technique and the spray up technique. Fabricating a composite part is generally concerned with placing and retaining fibres in the direction and form that is required to provide specified characteristics while the part performs its design function.

The methods of production will depend on factors such as cost, shape of components, number of components and required performance.

The manufacturing process can be classified into two broad categories:

- Hand methods
- Mould methods

Hand methods can be further classified into hand layup and spray up techniques. Moulding methods include Matched-die moulding and forming methods by employing gas pressure other processes include filament winding and pultrusion process.

HAND LAYUP TECHNIQUE

Hand lay-up refers to the manual method of laying or applying the reinforcement material into the mold. In the hand lay-up process, the reinforcing material (usually fiberglass mat) is placed in the mold and then saturated with polyester resin using a brush or a two-component spray system.

Advantages of hand layup techniques:

•Widely used for many years.

•Simple principles to teach.

•Low cost tooling, if room-temperature cure resins are used.

•Wide choice of suppliers and material types.

•Higher fibre contents and longer fibres than with spray lay-up.

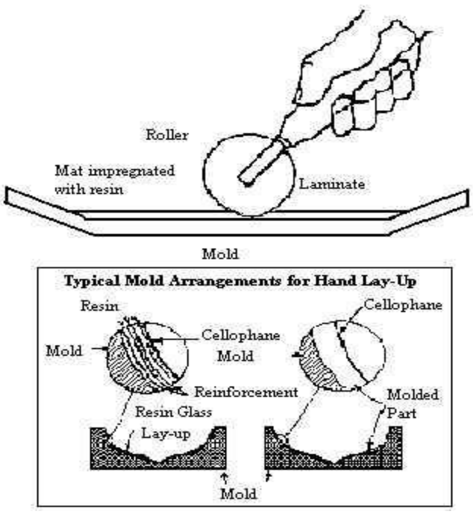


Figure 6
Hand lay-up technique

PROCEDURE FOR THE PREPARATION OF LAMINATED COMPOSITE PLATES

The composites have two components. The first is the matrix which acts as the skeleton of the composite and the second is the hardener which acts as the binder for the matrix. The reinforcement that was used for the project was woven glass fibres. Glass fibres are materials which consist of numerous extremely fine fibres of glass. It is used as a reinforcing agent for many polymer products; to form a very strong and light fibre (FRP) composite material called glass-reinforced plastic (GRP), popularly known as "fiberglass". The woven glass fibre was procured from the market and was used as the reinforcement for the composite.

The hardener that was utilized was epoxy. Epoxy is obtained as the last item in the wake of curing the saps. It is likewise utilized as a solid cement for staying things together and disguising surfaces. When poly epoxides respond with themselves or regular hardener then we get a thermosetting polymer, regularly with solid mechanical properties and high temperature and substance safety.

(a) Glass fibre

(b) Epoxy

Figure 7 Presents the individual component of the composite

HAND LAYUP PROCESS OF COMPOSITE MANUFACTURING

To manufacture the composites the following steps were followed.

1. The weight of the fibre was noted down. Then approximately 1/3rd mass of the hardener of epoxy was prepared for further use.
2. A clean plastic sheet was taken and the mould releasing spray was sprayed on it. After that a generous coating of the hardener mixture was coated on the sheet.A woven fibre sheet was taken and placed on top of the coating. After this again the coating of hardener was done. A second layer of fibre was placed and the process continued until the required thickness was obtained. The fibre was pressed with the help of rollers.
3. Another plastic sheet was taken and the mould releasing spray was sprayed on it. The plastic sheet was placed on top of the fibre with hardener coating.
4. The plate obtained was placed under weights for a period of 24 hours.
5. After that the plastic sheets were removed and the plates separated.

Figure 8 (a)

Figure 8 (b)

Figure 8 (c)

Figure 8 (d)

Figure 8 (e)

Figure 8 (f)

FABRICATION OF BUCKLING TEST RIG

The buckling test rig was developed in the Central Workshop of NIT Rourkela. The frame was built using rectangular shaped mild steel channels. The channels were welded to one another and then the frame was prepared. A 10 tonne hydraulic jack was assembled into the frame to provide the necessary hydraulic force for the compression of the plates. The setup can be assembled an disassembled at will as all its components can be separated. Thus the setup offers flexibility over the conventional buckling setups.

Figure 9: Lab scale hydraulic buckling test rig

ANSYS CODE DEVELOPMENT

ANSYS is an analysis software which makes use of FEA to study and analyse the behaviour of structures under various boundary conditions. An ANSYS code was developed which analysed the critical buckling loads of laminated composite plates. The material properties were picked from a journal and the results were validated. The results obtained were fairly accurate.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1. Results and Discussion

In this section, a simulation model has been developed in ANSYS parametric design language in ANSYS environment. The model has been compared and the convergence has been checked. Finally, the critical buckling load parameters are obtained for laminated plates for different mode shapes and thickness ratio.

The material properties used in the present analysis are as follows:

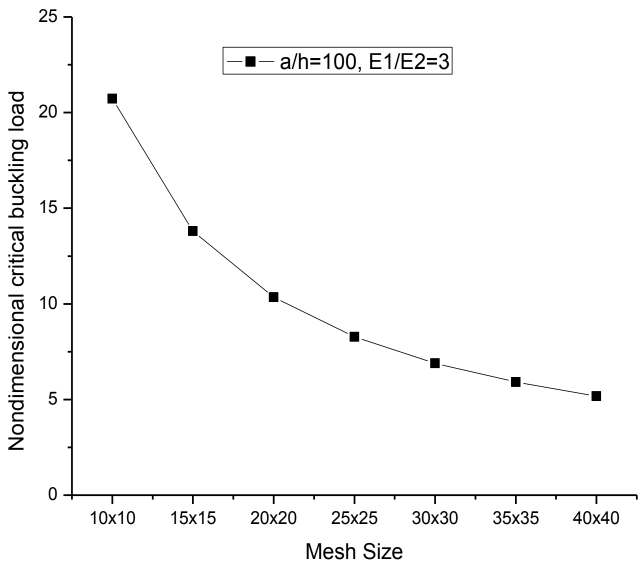
$E_{22}=1\times10^3$, $E_{11}=3E_{22}$ and $10E_{22}$, $E_{33}=E_{11}$

$G_{12}=G_{22}=0.6\times E_{12}$, $G_{23}=0.5\times E_{12}$

$\upsilon_{11}=\upsilon_{12}=\upsilon_{13}=0.25$

4.2 Convergence Study

In this section the convergence behaviour of laminated plate is obtained using the material, geometry and support conditions same as the reference [1]. It is clear that the present results are converging well with the mesh refinement.



4.3 Comparison Study

The present model is being validated by comparing the results with the reference by taking the same geometrical and material properties as well as the support conditions as stated in reference. The comparison study has been obtained for two different laminations and presented in Table 1 and Table 2. It is clear that the present results are showing good agreement with the reference and present results are showing higher side as compared to the reference. It is because of the fact that the present model is developed in the FSDT whereas in the reference the model is developed in the HSDT.

Table. 1 Comparison study of buckling load for cross ply [0/90/0] laminated composite plate.

a/*h*	E_{11}/E_{22}	Non-dimensional critical buckling load (N_{cr}) Present	Reference [1]
10	3	5.4702	5.3933
	10	8.6645	9.9406
100	3	6.8984	5.1245
	10	14.1641	11.4847

Table. 2 Comparison study of buckling load for cross ply [0/90/90/0] laminated composite plate.

a/*h*	E_{11}/E_{22}	Non-dimensional critical buckling load (N_{cr}) Present	Reference [1]
10	3	5.3215	5.4120
	10	9.7154	10.0130
100	3	5.6521	5.7616
	10	10.6945	11.4813

4.3.1 New Illustration

Here, in this section some new results are obtained for two different parameters (thickness ratio and orthotropicity) of simply supported cross-ply [0/90/90] laminated plate. The responses are presented in Table 3 and Table 4. It is observed that, the buckling load increases with thickness ratio and orthotropicity.

Table. 3: Effect of thickness ratio (a/h) on buckling load

a/h	Nondimensional Buckling load
10	3.3524
20	4.5964
50	5.0243
100	6.8746

Table. 4: Effect of thickness orthotropicity on buckling load

E_1/E_2	Nondimensional Buckling load
3	3.3524
10	4.1107
20	5.0457
30	5.8487

4.3.2Buckling mode shape

In this section first four mode shapes are for simply supported cross ply lamination and obtained using ANSYS and presented in the Fig. 10.

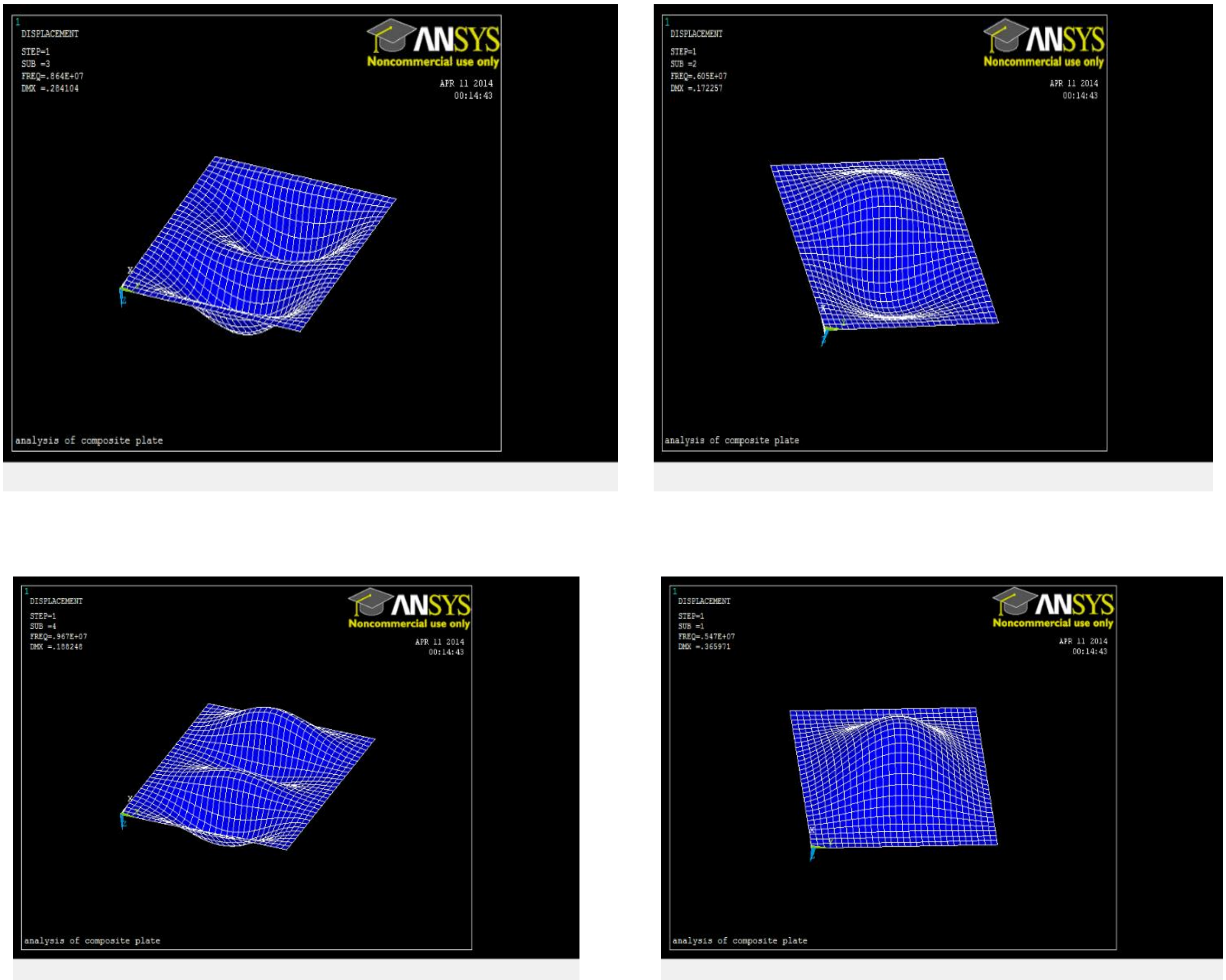


Figure 10: Different buckling mode shapes of laminated composite plate

CHAPTER 5

CONCLUSION

An APDL code was developed in ANSYS and the code was run. The dimensional critical buckling load and the non-dimensional critical buckling load were obtained. The non-dimensional critical buckling load obtained was compared with a standard literature. The results obtained were in agreement with the standard literature.

As the lamination scheme changes the critical buckling load does not get affected much. This is evident by the similar critical buckling loads obtained for the [0/90/0] and [0/90/90/0] composites.

The critical buckling load is strongly dependent on the elasticity along the X axis as is evident from the results obtained. The critical buckling load nearly doubles when the ratio E_1/E_2 changes from 3 to 10. This is because the plate is subjected to uniaxial loading along the X direction.

The locally manufacture buckling setup was prepared with very little cost and in a short span of time. This ensured that experiments can be conducted with the help of minimum cost and with a fair degree of accuracy.

CHAPTER 6

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